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Design of a Middle Scale Wave Energy Convertor of a PW-OWC type for a Sea Test in Sakata Port

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Abstract: This study proposes a wave energy convertion (WEC) of an air turbine type with an oscillating water column (OWC) equipped with projecting walls (PW), which is called a PW-OWC type wave energy convertor in the study. OWC type WECs have been major and studied in Japan over 30 years. Because an electrical generation device is installed out of water but in air, maintenance would be easier than submerged type one and such like devices would be able to be installed on existing breakwaters and wave dissipating caissons. Thus cost of electrical generation might be saved. This study remodeled a wave dissipating double-caisson to a WEC of the PW-OWC type and conducted an ocean-wave-resistant design in order to carry out a sea test of performances of power take-off (PTO), durability etc. Before that, basic performance of PTO was predicted from numerical model as well as well hydraulic experiments in a wave tank.

This paper shows the feature of PTO of the model device using results of as the experiments conducted at the wave tank and b) the field monit0rinng of a prototype model on existing seawalls which are located in the Sakata port facing to the Sea of Japan. Observed data are presented on turbine torque and generated electricity as well as incident waves.The paper shows an intern report of the sea test.

Keywords: wave power extracting breakwater, oscillating water column, projecting wall, model experiment

1 Introduction

Among the various wave power conversion systems, Oscillating Water Column System (OWC) has a long history of R/D. Owing to this research accumulation, its technical problems for practical use became clear. Those are mainly a) strong dependency of the primary conversion efficiency on the incident wave period, b) relatively low efficiency of the secondary conversion under reciprocating air current and c) expensive mooring cost for offshore facilities.

Though incident waves bring energy with wide range of wave period, the primary conversion of conventional systems from wave to air flow was attained high efficiency only under the narrow band of wave period. Reciprocating air current generated after the primary conversion often required a tandem type turbine system to improve slow response. Offshore mooring system was relatively expensive especially in the deep sea with rough wave climate. This paper discussed mainly on the above topics .

2 Effect of projecting-wall and installation on breakwater

Hydraulic experiments with small and large scales (S:1/25 – 1/7) were conducted to improve the primary conversion from wave to air flow for wider range of incident wave periods. Projecting-walls (PW), installed both side of the opening (see Fig.1), proved to make frequency dependency reduced.

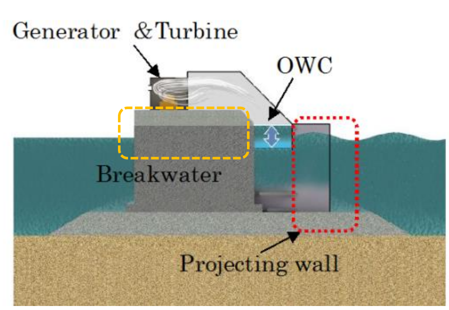

Fig.1 Concept of PW-OWC type wave energy convertion(WEC) breakwater

2.1 Hydraulic model experiments of PW [1),2)]

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Hydraulic experiments in regular waves were conducted to evaluate the effect of projecting-wall. Primary energy conversion efficiency (E) was compared for the single OWC facility with and without PW.

The definition of E is shown in Eq.(1) for the power of incident wave (PI) and the power of converted air power (PA).

$$\mathrm{E} = \frac{P_A}{P_I} \tag{1}$$

PI is expressed as Eq.(2), and PA as Eq.(3),.

$$P_I = \frac{\rho g 2a2}{8\pi}\left(1 + \frac{2kh}{sinh2kh}\right)(\tanh kh)TB \tag{2}$$

$$P_A = \frac{AW}{T}\int_0^T P(t)\frac{\partial\,\overline{\eta}(t)}{\partial t}dt \tag{3}$$

where; a: amplitude of incident wave, B: width of airchamber, T: wave period, h:water depth, k: wave number, AW: line area of water surface, P: pressure in airchamber, ρ: water density, and η: amplitude of watersurface fluctuation in airchamber.

With PW, double peaks of resonance were found for the airflow extraction against the incident wave period. Moreover, conversion efficiency for the longer period of waves was found relatively high due to PW. As longer period of waves brings high energy to the facility than shorter period, this character can be effective to improve the relative primary conversion efficiency.

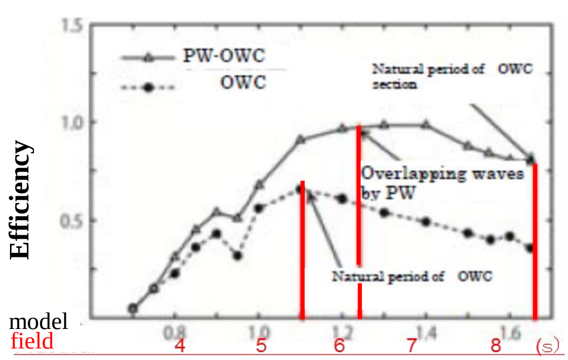


Fig.2 Efficiency comparison for OWC & PW-OWC

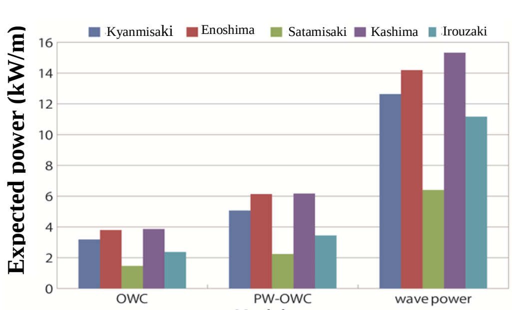


Fig.3 Generation power by OWC for 5 ports with / without PW

2.2 Estimation of converted power for different sites

Applying the conversion efficiency curve obtained, estimation was tried of the converted power for the different wave climates at five sites, those are; Cape Kyan, Ejima, Cape Sata, Kashima, and Cape Iroh. For each site, the frequency distribution of the incident waves against wave period is provided by JAMSTEC (2004). Results are shown in Fig 3.

Under various wave condition, PW-OWC provides higher conversion efficiency by 1.5 - 1.7 than OWC without PW.

2.3 Interference by reflection waves [1),3)]

Then we started planning a field experiment to evaluate the effect of PW-OWC with new turbine (impulse turbine). Our first target for PW-OWC installed on was outer breakwater. When a single PW-OWC was placed alone in the middle of a breakwater line, a sudden drop of E was calculated due to the interference by reflection waves from the breakwater line (Fig 4). In this Figure, dots are plotted for the observed E's at the hydraulic experiments (S=1/36) using the PW-OWC scale model. Sudden drop was occurred at around T=7.5s.

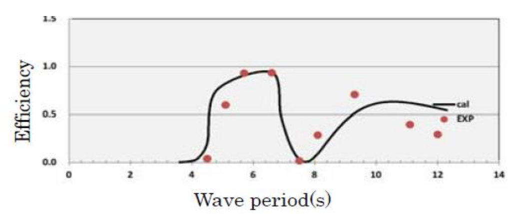
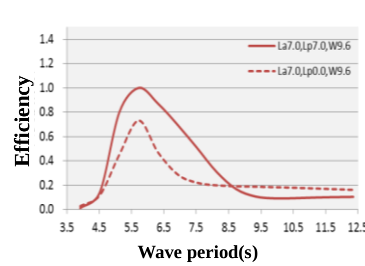
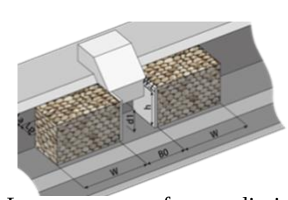


Fig.4 Response of E against wave period
(line : calculation result, dots: experiment results)

In the case when a PW-OWC sets offshore alone without breakwater and in the case when many PW-OWC's set side-by-side along breakwater line, this drop could not be found. Accordingly, decrease of reflection energy from ambient breakwater is expected one of the practical countermeasures against this drop.

Assigning a reduced reflection-factor from backed breakwaters (supposing placement of enough wave - dissipation blocks on the breakwater), this drop disappeared as shown in Fig 5.





Large amount of wave dissipating structure is necessary.

expensive and un realistic

Fig.5 Improvement of E after reflection reduction
(solid line: reflection reduction, dotted line: no reduction)

3 Field experiment designing

3.1 Experiment facility of WEC

In order to avoid the wave-reflection problem, we put wave dissipation type facilities on the table.

Sakata port has fortunately a line of unique wave-dissipation seawalls of up-right type Our experiment facility is now shifted to install on this inner seawall.

This seawall has two chambers inside, a fore-chamber and a back-chamber. Two chambers are connected by the openings. Incident waves can go into these chambers freely. Top of each chamber is open to the air(Fig. 6).

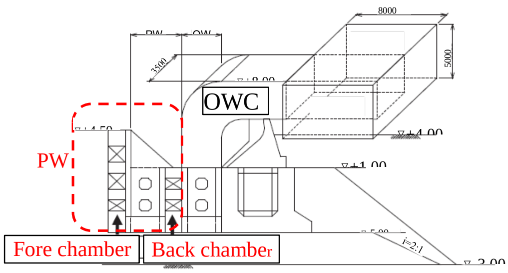


Fig.6 PW-OWC installed on the seawall in Sakata Port (The fore-chamber with side wall can be act as PW)

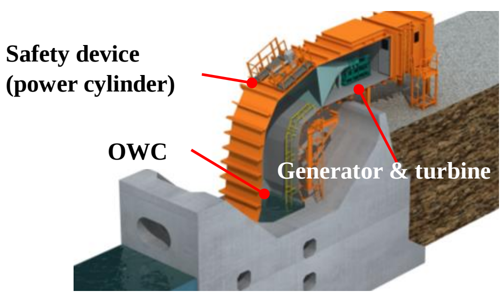


Fig.7 Conceptual design of PW-OWC on the seawall

Fig.7 shows the conceptual design of the WEC facility which is installed on the existing seawall in Sakata Port.

We use the fore-chamber as PW, and the back-chamber as OWC (Oscillation Water Colum). Both chambers are same-size W3.5m ×L3.5m ×H5.5m). Incident wave is usual small except winter, when $H_{1/3}$ &$T_{1/3}$ for the design of seawall was 6.0(m), 14(s) , respectively..

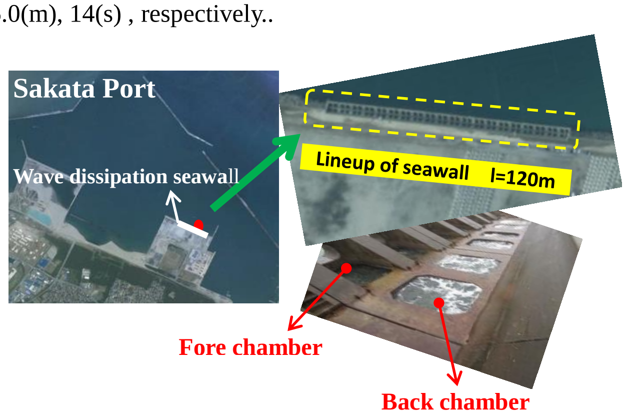


Photo.1 Locating of wave-dissipation seawall

Based on the above concept, we carried out the design of wave power generation apparatus for field experiments in the Port of Sakata.(Photo.1)

For structure designing, we choose main design parameters as follows;

a) OWC air chamber pressure,
b) wind load.
c) seismic inertial force.

3.2 Installation of WEC facility

Construction was started in December, 2014. Unit blocks at suitable dimensions in consideration of load-trucking were manufactured mainly with steel at iron factory.

Photo.2 Power generation facility under installation (Dec.2014)

Photo.3 Wave power generation facility completed (Jan.2015)

On site, the base-unit was first installed on OWC (back-chamber). Then, the middle and upper parts of the units was attached on it, as shown photo.2. Due to the stormy weather, it took around 2 weeks to finish installation of the WEC facility on the seawall. Photo.3 shows the appearance of the whole facility after the completion of installation work, the left side is sea. The facility steps over the concrete parapet on the seawall.

4 Power generation situation

Generation was started from January 17, 2015 after the official inspection for the safety under Enterprises Law. Up to 13kW was observed on March 5, 2015.

4.1 Generation properties

Under reciprocating air flow, the impulse turbine and generator generated electricity. The power of generation is expressed as a product of the outbreak torque (turbine torque) and the turbine number of revolutions (rpm).

Fig.8 shows the relationship between turbine torque and incident waves. X-axis expresses time (hours: minutes: sec.) on the same date of January 31, 2015. All data were sampled every 0.1sec (10Hz). Both aspirating and inspiriting phases, positive values of torque were monitored (blue line in upper figure in Fig.8). When looking at Fig.8 closely, we found that zero-torque (very weak torque) was observed. Blue arrows in fig.8 indicate the occurrence of torque-zero (upper figure in Fig.8), when the change of water level was slow in OWC (lower figure in Fig.8).

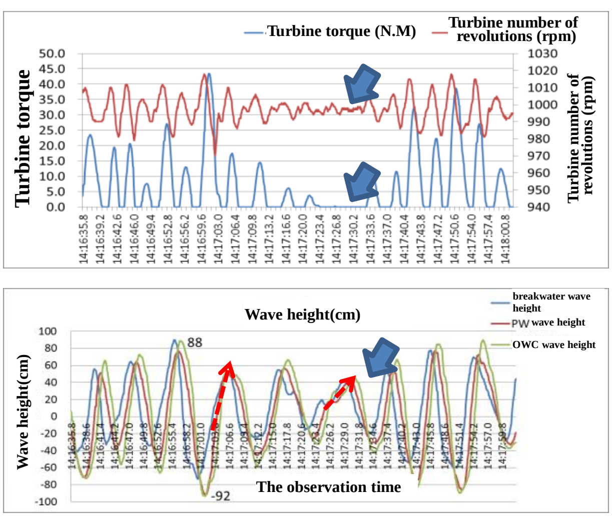


Fig.8 A time change (from 16 to 18 minute at 14 o'clock on Jan.31) of the wave height and outbreak turbine torque and turbine number of revolutions

4.2 Relations between air pressure and turbine torque

We also found in Fig.8 that the torque falls down to zero when the direction of air flow changes. The scatter diagrams of air chamber pressure and the turbine torque are presented in Fig.9 and 10, observed on February 13 and January 31, 2015,respectivery.. The right side of each figure expresses anseism (positive) pressure (aspirating phase), and the left side minus (negative) pressure (inspiriting phase). The platted dots in both figures are asymmetric. In Fig.9, turbine torque as well as generated electricity shows larger efficiency when the air flow is anaseism (aspiring). On the other hand, in Fig.10, generation is more effective when the air flow is negative (inspiriting). Observed wave at OWC was $H_{1/3}$=1.9m, $T_{1/3}$=7.1s February 13 for Fig.9, and $H_{1/3}$=0.7m, $T_{1/3}$=5.5s, on January 31for Fig.10. Wave energy or changing rate / speed of water level in OWC may cause the different response of turbine. Research should be continued to clarify the response process of turbine to different incident waves.

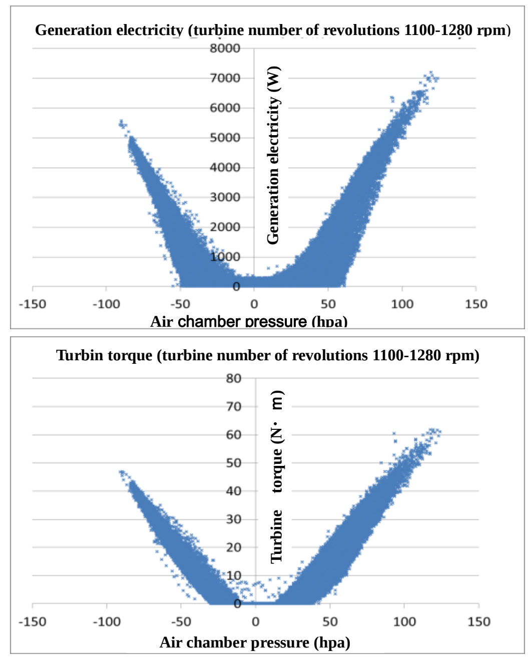


Fig.9 Air chamber pressure and generation properties (February 13)

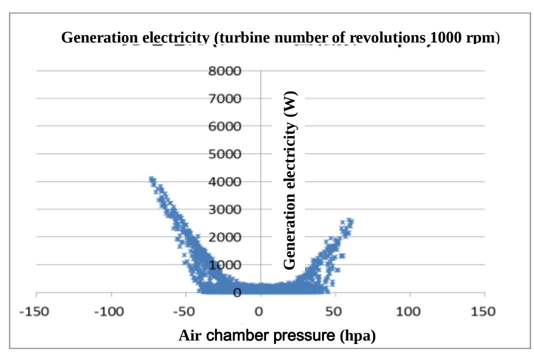


Fig.10 Air chamber pressure and generation properties (January 31)

4.3 Comparison between design value and observed value of air pressure

The comparison is conducted between observed values and calculated values of the air pressure caused by the surface of the water change in the air chamber. The amplitude of air – pressure change is plotted against the incident wave height. Observed data in Fig.11 are monitored on February 13, 2015. Calculated values are based on the liner transfer motion theory[4),5)] . Though data are limited, observed data agrees relatively well with calculated values.

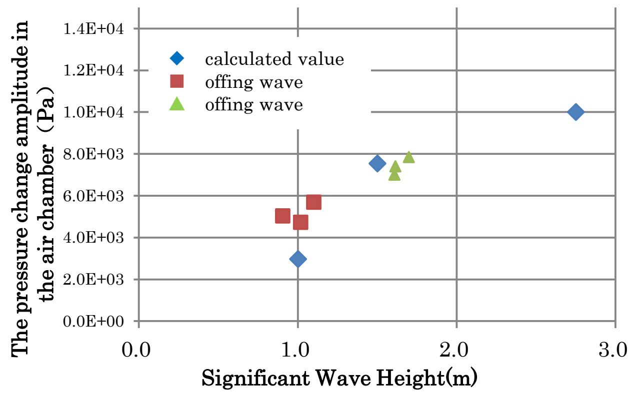


Fig.11 Comparison between observed value and calculated value of the pressure in the air chamber

5 Conclusions

1) The primary conversion of OWC facility can be expected higher by the factor of around 1.5 after applying PW. This is due to the better response for the longer wave period by the improvement of the wave period dependency.
2) PW-OWC is influenced by the reflection waves from the backed breakwater when it is installed alone. Reduction of the reflection from the breakwater produces notable recovery of the primary conversion.
3) PW-OWC system can be applied to the existing wave-dissipation seawall of upright-type. Installation design is proposed.
4) A PW-OWC type WEC was installed on the existing seawall in Sakata Port. Field experiment of generation was started since January 2015. This application of PW-OWC was mainly concentrated into winter waves. Monitoring and analysis are still be continued.
5) The response of turbine torque and electricity generation varies in accordance with the strength of the incident wave height.
6) To the pressure change in the air chamber (OWC), the simulation method based on the linear transformation is applicable.

6 Acknowledgements

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